(12) **United States Patent**
Li et al.

(10) **Patent No.:** **US 7,236,748 B2**
(45) **Date of Patent:** **Jun. 26, 2007**

(54) **CLOSED LOOP FEEDBACK IN MIMO SYSTEMS**

(75) Inventors: **Qinghua Li**, Sunnyvale, CA (US); **Xintian E. Lin**, Palo Alto, CA (US)

(73) Assignee: **Intel Corporation**, Santa Clara, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 363 days.

(21) Appl. No.: **10/955,826**

(22) Filed: **Sep. 30, 2004**

(65) **Prior Publication Data**

US 2006/0068738 A1   Mar. 30, 2006

(51) **Int. Cl.**
H04B 1/38   (2006.01)
H04M 1/00   (2006.01)
(52) **U.S. Cl.** **455/69**; 455/562.1
(58) **Field of Classification Search** 455/69, 455/562.1, 561, 101, 103, 272–273, 276.1, 455/277.1, 277.2; 375/299, 347; 370/208
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,999,826 A	*	12/1999	Whinnett	.... 455/561
6,597,678 B1	*	7/2003	Kuwahara et al.	.... 370/342
6,847,805 B2	*	1/2005	Liu	.... 455/69
6,927,728 B2		8/2005	Vook et al.	

2003/0125040 A1	*	7/2003	Walton et al.	.... 455/454
2003/0210750 A1	*	11/2003	Onggosanusi et al.	...... 375/295
2004/0235433 A1	*	11/2004	Hugl et al.	.... 455/101
2005/0101259 A1		5/2005	Tong et al.	
2005/0286663 A1		12/2005	Poon	
2006/0056335 A1		3/2006	Lin et al.	
2006/0056531 A1		3/2006	Li et al.	
2006/0068718 A1	*	3/2006	Li et al.	.... 455/69
2006/0092054 A1		5/2006	Li et al.	

OTHER PUBLICATIONS

International Search Report and Written Opinion of the International Seraching Authority; Dated Jan. 31, 2006; PCT/US2005/031585, 1-13.
International Search Report and Written Opinion of the International Searching Authority; Dated Sep. 16, 2005; PCT/US2005/017774; 15 Pages.
"PCT Search Report", PCT/US2005/031979, (Jan. 23, 2006), 12 pages.
Jihoon, C. , "Interpolation based transmit beamforming for MIMO-OFDM with Limited Feedback", *IEEE International Conference on Paris, France, Piscataway, NJ, USA*., P20442PCT—PCT Search Report Written Opinion from PCT application serial No. PCT/US2005/031585,(Jun. 20, 2004),249-253.
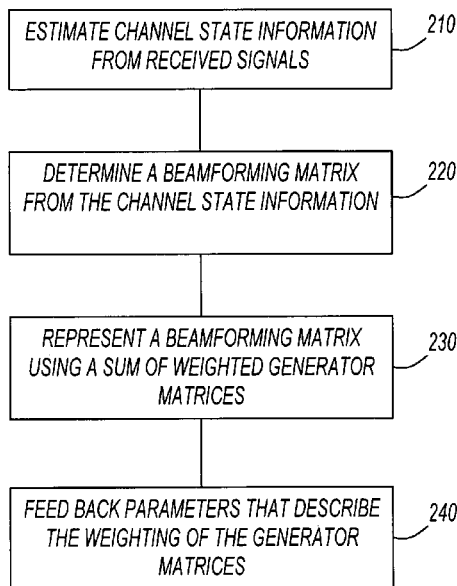
* cited by examiner

Primary Examiner—Nguyen T. Vo
(74) *Attorney, Agent, or Firm*—LeMoine Patent Services, PLLC; Dana B. LeMoine

(57)   **ABSTRACT**

Feedback bandwidth may be reduced in a closed loop MIMO system by representing a beamforming matrix using orthogonal generator matrices.
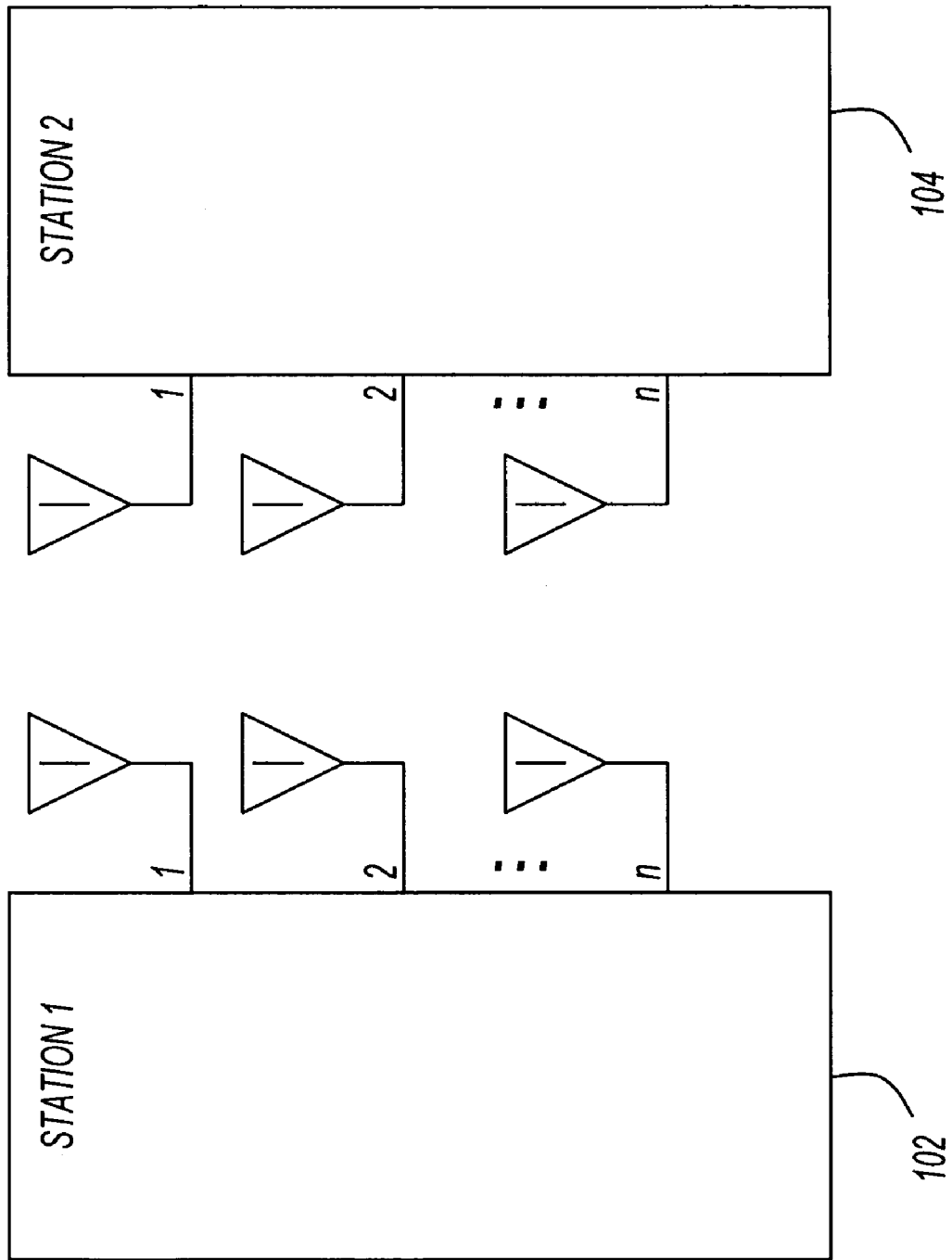
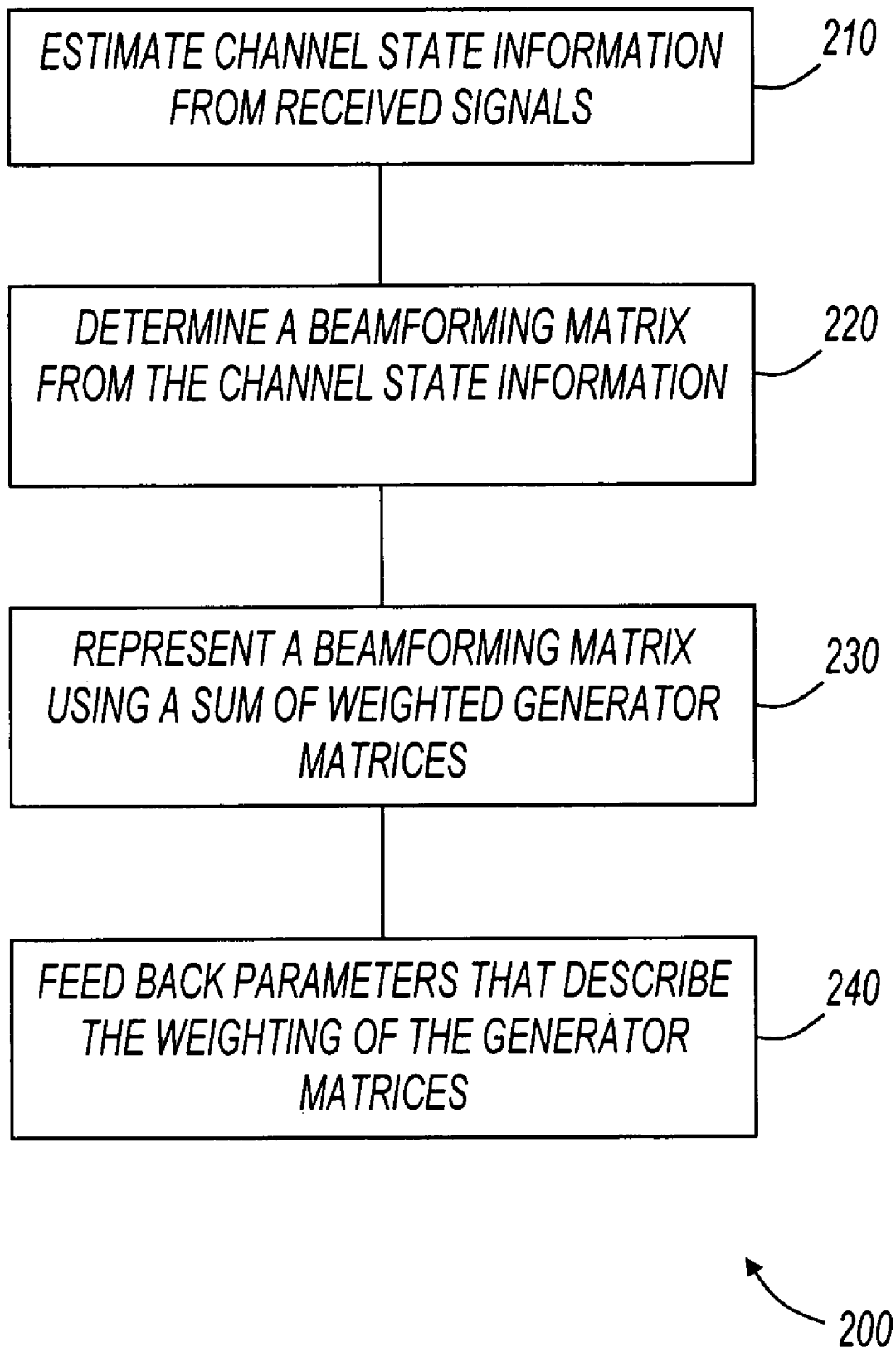**23 Claims, 4 Drawing Sheets**

FIG. 1

```
┌─────────────────────────────────────────┐
│   ESTIMATE CHANNEL STATE INFORMATION     │──── 210
│        FROM RECEIVED SIGNALS             │
└─────────────────────────────────────────┘
                    │
┌─────────────────────────────────────────┐
│   DETERMINE A BEAMFORMING MATRIX         │──── 220
│   FROM THE CHANNEL STATE INFORMATION     │
└─────────────────────────────────────────┘
                    │
┌─────────────────────────────────────────┐
│   REPRESENT A BEAMFORMING MATRIX         │──── 230
│   USING A SUM OF WEIGHTED GENERATOR      │
│              MATRICES                    │
└─────────────────────────────────────────┘
                    │
┌─────────────────────────────────────────┐
│   FEED BACK PARAMETERS THAT DESCRIBE     │──── 240
│   THE WEIGHTING OF THE GENERATOR         │
│              MATRICES                    │
└─────────────────────────────────────────┘
```

200

FIG. 2

RECEIVE AT LEAST ONE PARAMETER — 310

WEIGHT AT LEAST ONE GENERATOR MATRIX USING INFORMATION DERIVED FROM THE AT LEAST ONE PARAMETER — 320

COMBINE THE AT LEAST ONE GENERATOR MATRIX TO ARRIVE AT A BEAMFORMING MATRIX — 330

300

FIG. 3

ETHERNET INTERFACE 450
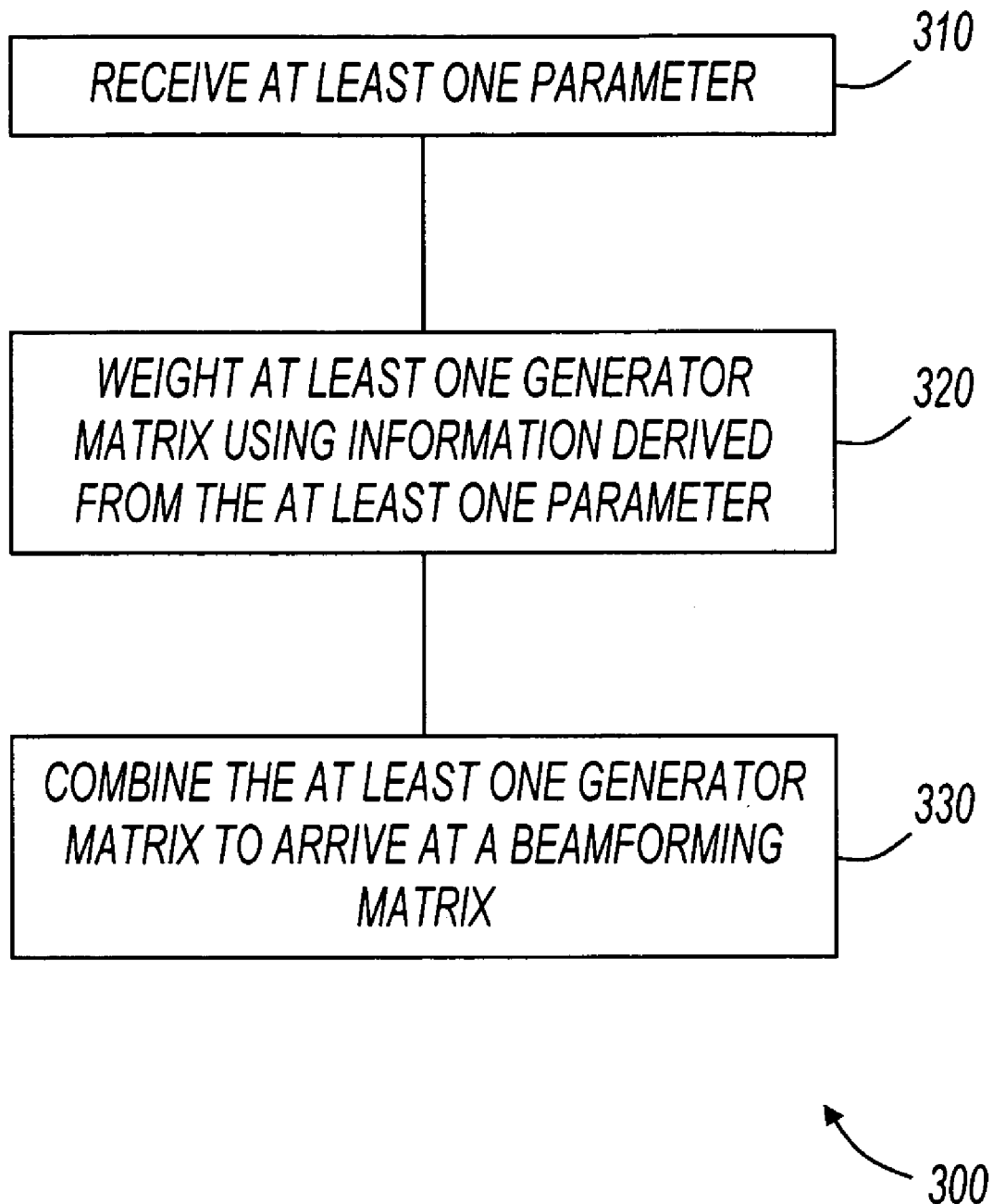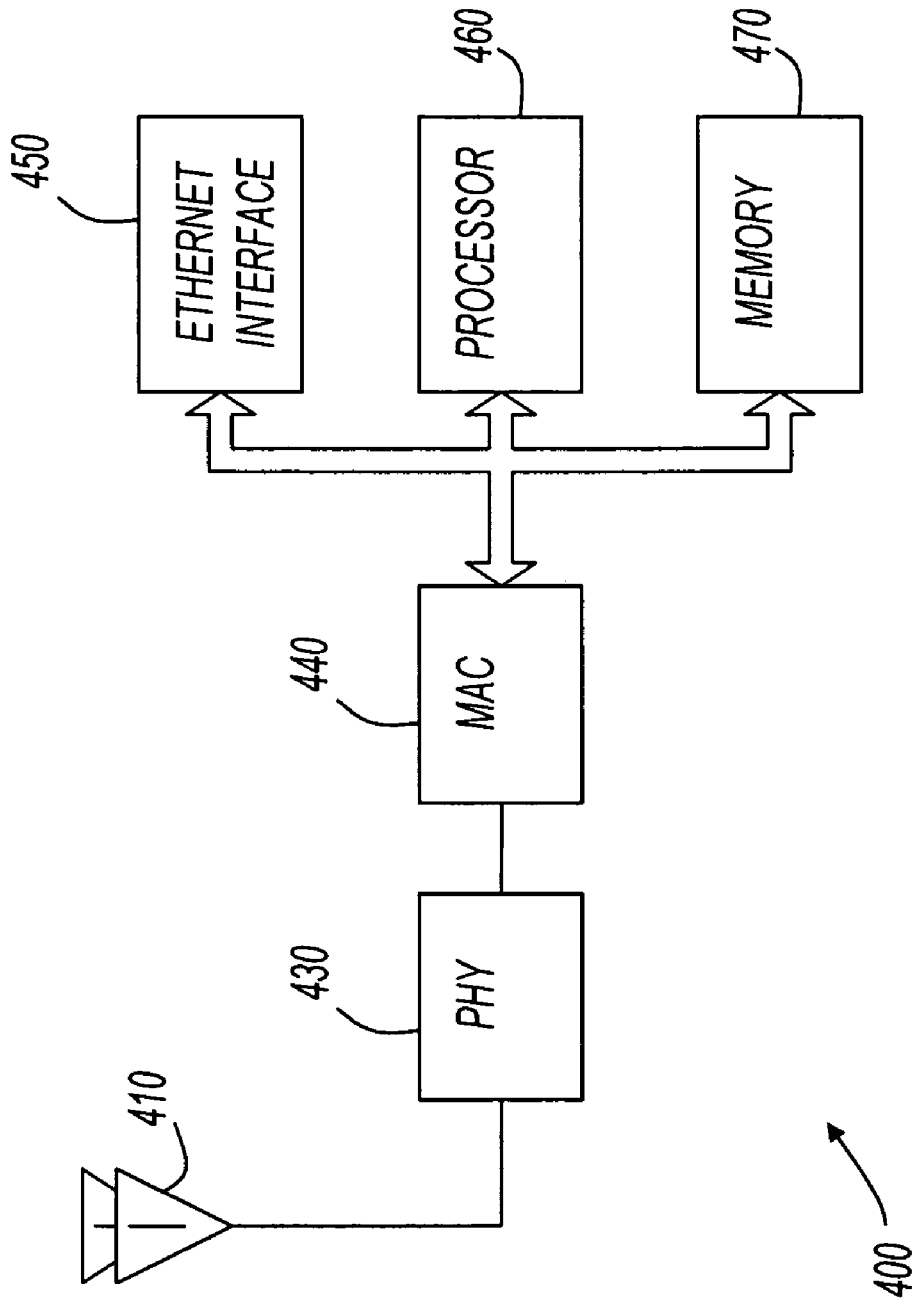
PROCESSOR 460

MEMORY 470

MAC 440

PHY 430

410

400

FIG. 4

Explore Litigation Insights

Docket Alarm provides insights to develop a more informed litigation strategy and the peace of mind of knowing you're on top of things.

Real-Time Litigation Alerts

Keep your litigation team up-to-date with **real-time alerts** and advanced team management tools built for the enterprise, all while greatly reducing PACER spend.

Our comprehensive service means we can handle Federal, State, and Administrative courts across the country.

Advanced Docket Research

With over 230 million records, Docket Alarm's cloud-native docket research platform finds what other services can't. Coverage includes Federal, State, plus PTAB, TTAB, ITC and NLRB decisions, all in one place.

Identify arguments that have been successful in the past with full text, pinpoint searching. Link to case law cited within any court document via Fastcase.

Analytics At Your Fingertips

Learn what happened the last time a particular judge, opposing counsel or company faced cases similar to yours.

Advanced out-of-the-box PTAB and TTAB analytics are always at your fingertips.

API

Docket Alarm offers a powerful API (application programming interface) to developers that want to integrate case filings into their apps.

LAW FIRMS
Build custom dashboards for your attorneys and clients with live data direct from the court.

Automate many repetitive legal tasks like conflict checks, document management, and marketing.

FINANCIAL INSTITUTIONS
Litigation and bankruptcy checks for companies and debtors.

E-DISCOVERY AND LEGAL VENDORS
Sync your system to PACER to automate legal marketing.